Effect of Surface Roughness on X-ray Fluorescence Emission from Planetary Surfaces

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Laboratory experiments are being performed to understand x-ray fluorescence phenomena on regolithed or rocky planetary surfaces, which happens on the day side of atmosphere-free planetary surfaces of Mercury, the Moon, satellites, and asteroids. Our results are quite preliminary but show clear tendency dependent on the surface roughness with sub-millimeter scale, corresponding to the representative diameter of the Apollo lunar soils. This fact is considered important for remote-sensing x-ray fluorescence experiments to make a quantitative elemental analysis and maybe useful for estimation of average particle size of regolith layer from orbiting spacecraft in the future planetary missions.

Introduction

X-ray fluorescence is well-developed technique for qualitative and quantitative elemental analysis in the laboratory. The incident x-rays from an exciting source generate x-ray fluorescence from the specimen and its spectrum reflects the elemental composition. Similar phenomenon happens on the planetary surfaces with solar x-rays and uppermost surface materials. Irradiation of solar x-rays always excite fluorescent x-rays of major rock-forming elements, e.g., Mg, Al, Si, enough to detect from orbiting or trajectory altitude of the planet. Therefore major elemental mapping of the planetary surfaces can be carried out with concurrent observation of x-rays from the sun and the planet.

The uppermost layer of planetary surfaces are often covered with regolith whose average diameter ranges tens to hundreds micrometer. The geometry of the surface layer should be not only rough but porous, and very different from the ideal flat features usually used as specimen for x-ray elemental analysis in the laboratory. It is generally regarded that the roughness with amplitude of more than 10 micrometer may take effects on the spectral profile and overall intensities of x-ray fluorescence, thus on quantitative analysis. During Apollo missions, the detecting system was so poor by using conventional proportional counters with selected filters that there is no need to take care of the surface conditions for the method of analysis at that time. However, recent improvement of x-ray fluorescence spectrometer with Gas Scintillation proportional Counters or Charge-Coupled Devices used as the detectors enables us to perform high-accurate spectrometry of the planetary surfaces with variety of incident and emission angles. Then the surface geometric features as well as elemental composition must be taken into account for the planetary x-ray fluorescence experiments, especially in oblique solar-angle or non-zero sun-planet-spacecraft phase angle conditions.

Experiments

In order to estimate the effect of surface roughness on the x-ray fluorescence spectrometry, we developed a experimental apparatus with using x-ray tubes, a goniometer, a helium-chamber, and a peltier-cooled avalanche photodiode module as the energy-dispersive x-ray spectrometer. We simulated the planetary regolithed surfaces with the specimen of properly mixed SiC and Alumina powder compounds with various sets of average diameter from 5 to 150 micrometer, and the surface roughness are under control by changing mixing ratio. The specimen are set in the holders which are mounted at the center of goniometer. The sample holders and the turntables of goniometer were placed in the helium chamber filled with the helium gas flown from the gas cylinder. The chamber has many x-ray windows made of thin polyethylene film; one large window for incident x-rays from the x-ray tube, and the others to attach the x-ray detector. The line x-rays of exciting source were mainly generated by use of combination of Cr target and V filter, and collimated by slits to radiate into the surface of specimen. Both of fluorescent and coherently scattered x-rays were excited and emitted in all the directions but angular dependence of intensity profile may exist. The phase angles of source-specimen-detector are selected every 5 degree by changing attachment position of the detector. On the other hand, the incident and emission angles can be altered by rotation of the sample-holders. To obtain referential data set, flat metal plates of Ti and Al were also used.

Results

The results show the intensities of x-ray fluorescence vary with the incident and emission angles, phase angles, and surface roughness of the target specimen. The dependence of incident angles were obvious and the stronger intensities were observed with increasing incident angles. However, no effect of surface roughness were found for the variety of specimen and referential flat Al plate; their relative intensities are about the same at any incident angles we observed (0 to 60 degree). On the other hand, the dependence of phase angles were much clearer for the same ratio of incident-emission angles. At larger phase angles, the intensities of x-ray fluorescence were so reduced, especially at the smaller incident angles. It is evident that the effect of surface roughness exists; the roughness with more than 50 micrometer amplitude, or particle size in these cases, decreases its intensities at the smaller and the very large incident angles. These phenomena may be explained by the shield effect of x-ray fluorescence emission and the shadow effect of source x-ray incidence, respectively.

Conclusions are that particle size effect which makes surface roughness surely exists but reveals only 10% differences in relative intensities regardress of parficle sizes, except for high or low incident angles or large phase angles. Although 10% is not so large, the differences are sufficiently detectable with improved x-ray spectrometers.

Discussions

Our results are still primitive but it may be able to assert relative intensities of each x-ray fluorescence of major rock-forming elements are less than 10%, therefore rock-types of the uppermost regolithed layers are determinable through remote-sensing x-ray fluorescence experiments. Since more accurate elemental analyses should be expected in the future missions like MUSES-C (asteroid) and SELENE (Moon), some empirical method or theoretical understanding for quantitative analysis have to be established by laboratory experiments and numerical modeling. Our recent numerical study points out that the particle size effect has two main components: surface roughness and porosity. The former seems more effective on the planetary surfaces, because the continuum component of solar x-rays with energy just above the K-edge of each element excites the x-ray fluorescence so effectively that the absorption coefficients for incident and emission x-rays are comparable due to proximity of their energy. Though the method should be much improved, correction formulae against non-ideal planetary surfaces will be constructed, at least empirically. Furthermore, understanding the effect can implies possibility that the phenomenon can be used to estimate representative particle size of planetary surfaces through x-ray fluorescence experiments with high-resolution detectors like CCDs.